PS A Renewed Focus on Utah's Helium Potential*

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Abstract

For nearly 100 years the naturally occurring noble gas, helium, has been documented in the gas stream of natural gas wells in eastern Utah. Demand for helium is growing and the U.S. Bureau of Land Management is nearing completion of a prolonged exit from its dominant position in the commercial helium business. This transition creates opportunity for focused exploration of helium in eastern Utah and the Four Corners region of the Colorado Plateau. As supply diminishes and global demand for helium rises, primarily in the medical, technology and defense industries, economic consideration of helium exploration and production from helium-rich gas streams outside of proven natural gas productive areas is likely to significantly increase. A volume concentration of helium found in the gas stream of 0.3% or more is considered a potential helium resource. Concentrations of helium over 7.0% are rare, yet have been discovered and documented in the gas stream of wells drilled in east central Utah.

Helium (He) forms primarily in granitic or crystalline crustal rock as the alpha decay product of various radioactive elements. In southeastern Utah, reactivation of Precambrian suture zones, formed during the initial accretion of the western North American Cordillera, may provide pathways for helium microseepage to the surface. Through groundwater interaction, the buoyant decay products of deep-seated granitic or crystalline basement rocks can travel up fractures and faults until constrained in conventional hydrocarbon traps. Mantle degassing and breakdown of uranium ore bodies within thick sequences of sedimentary rock may also contribute significantly to the accumulation of helium in the subsurface. In Utah, high helium gas is typically concentrated at the margins of proven petroleum fields in deep vertical natural gas wells with high associated concentrations of nitrogen (N_2) and/or carbon dioxide (CO_2). Helium-rich gas streams in Utah are often found reservoired below the Paradox Formation salt or below the thick Mancos Shale.

While many helium-prospective regions may exist, very few natural gas fields contain the concentrations necessary to justify a helium recovery process. Documented helium shows in Utah range from common trace amounts up to 7.31%, with the highest helium concentrations on the crest of the Harley Dome structure in east central Utah from the Entrada Sandstone reservoir. Although eastern Utah helium prospects have been documented since the early 20th century, recent renewed interest of several upstream helium exploration and production companies has

brought attention back to the helium potential of Utah. With several high-percentage helium plays and natural gas wells with associated helium concentrations at or above the 0.3% economic threshold, Utah deserves the consideration of those interested in exploring for and producing helium.

A Renewed Focus on Utah's Helium Potential

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State of Utah School & Institutional Trust Lands Administration

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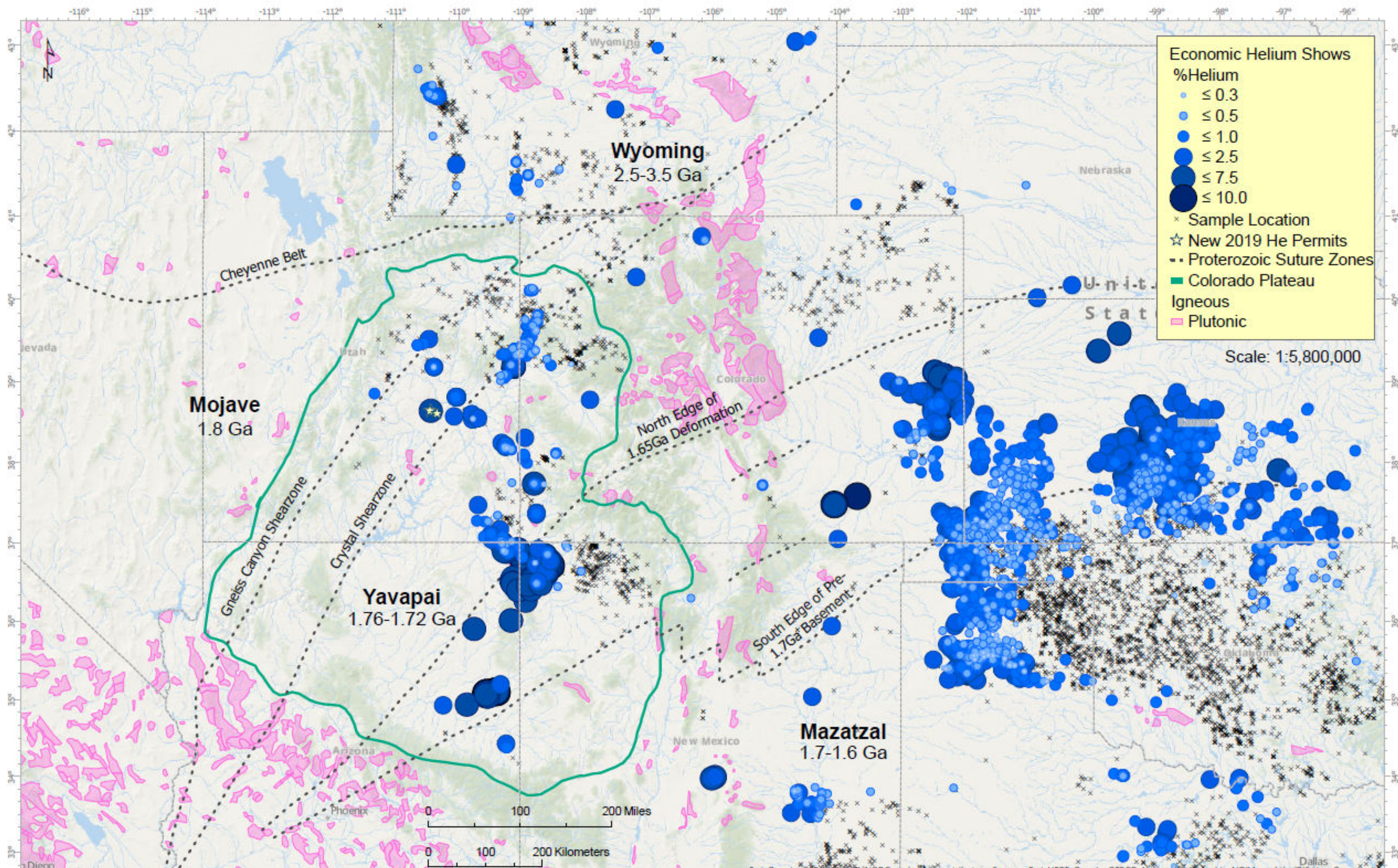


Graduated symbol map showing the major helium trends in the United States clustered near northeast trending Proterozoic accretionary boundaries. Note that the greatest density of helium analyses are from the gas stream of wells drilled in the depleting Hugoton-Panhandle gas field complex throughout Kansas, Oklahoma and Texas. Other significant helium analyses are shown clustered in the Four Corners region within the interior of the Colorado Plateau region. Colorado Plateau outline modified from Fenneman and Johnson (1946). Helium and igneous pluton data modified from U.S. Geological Survey (2015). Proterozoic suture zones modified from Karlstrom and Humphreys (1998).

Executive Summary

Helium is a rare and exhaustible resource found in recoverable quantities during natural gas production in very few locations globally, many of which are being actively depleted. The peculiar properties of helium (e.g. inert, non-toxic, lighter-than-air, ultra-cool melting temperature and small molecular size) make it an element that can be used in a variety of commercial, industrial, medical, military and research applications as both a liquid and a gas. Continued demand for helium will depend on a range of factors, but for many cutting-edge scientific and medical diagnostic applications helium is unique and has no known replacement.

In the United States, varied amounts of helium and associated non-hydrocarbon gases occur frequently as a byproduct during natural gas production throughout Arizona, Colorado, Kansas, New Mexico, Oklahoma, Texas, Utah and Wyoming. Currently, these mid-continent, Colorado Plateau and Rocky Mountain regions of the United States combine to represent the majority of the refined helium supplied to the rest of the world, with Algeria, Poland, Qatar and Russia noted as other significant helium producers. Recent studies in Africa suggest that countries bordering the East African Rift Valley, specifically Tanzania, have the potential to become a major helium producer in the near future. While many helium play areas may exist, very few developed natural gas fields are large enough or contain the concentrations necessary to justify a helium recovery process. Although a gas flow helium content of 0.3% may be considered a helium resource, the concentration at which extraction is economically feasible usually depends on transportation, adequate storage capacity and how the hydrocarbon and associated gas will be processed.

For oil and gas wells drilled in southeastern Utah, documented helium and non-hydrocarbon gas stream data is typically better preserved in the well file for older wells, particularly those drilled from the 1940s into the 1970s. This observation may originate because drill stem tests (DST's) were commonly used during the frontier exploration phase to obtain fluid and pressure data from a geological formation during the drilling of a well before more sophisticated wireline logging tools were developed. This results in fewer gas stream analyses in more recently drilled wells, especially within the intervals most prospective for helium.

With three minor exceptions, the economic helium concentrations in Utah are located in Carbon, Emery, Grand and San Juan Counties. Higher carbon dioxide gas streams seem to cluster in structural lows closer to the edges of the Colorado Plateau, primarily along the northern limb of the San Rafael Swell. This observation supports research by Gilfillan and others (2008) that suggests carbon dioxide in the gas stream is predominantly magmatic due to the close proximity to major volcanic fields on the margins of the Colorado Plateau. In contrast, gas streams with higher concentrations of nitrogen and helium tend to occur along the margins of known petroleum fields in association with structural highs within the plateau interior and within close proximity to zones of weakness from basement-involved tectonic events. Outliers with marginal economic amounts of helium have been documented in Sevier County of central Utah as well as Daggett County in the far northeast part of the state.

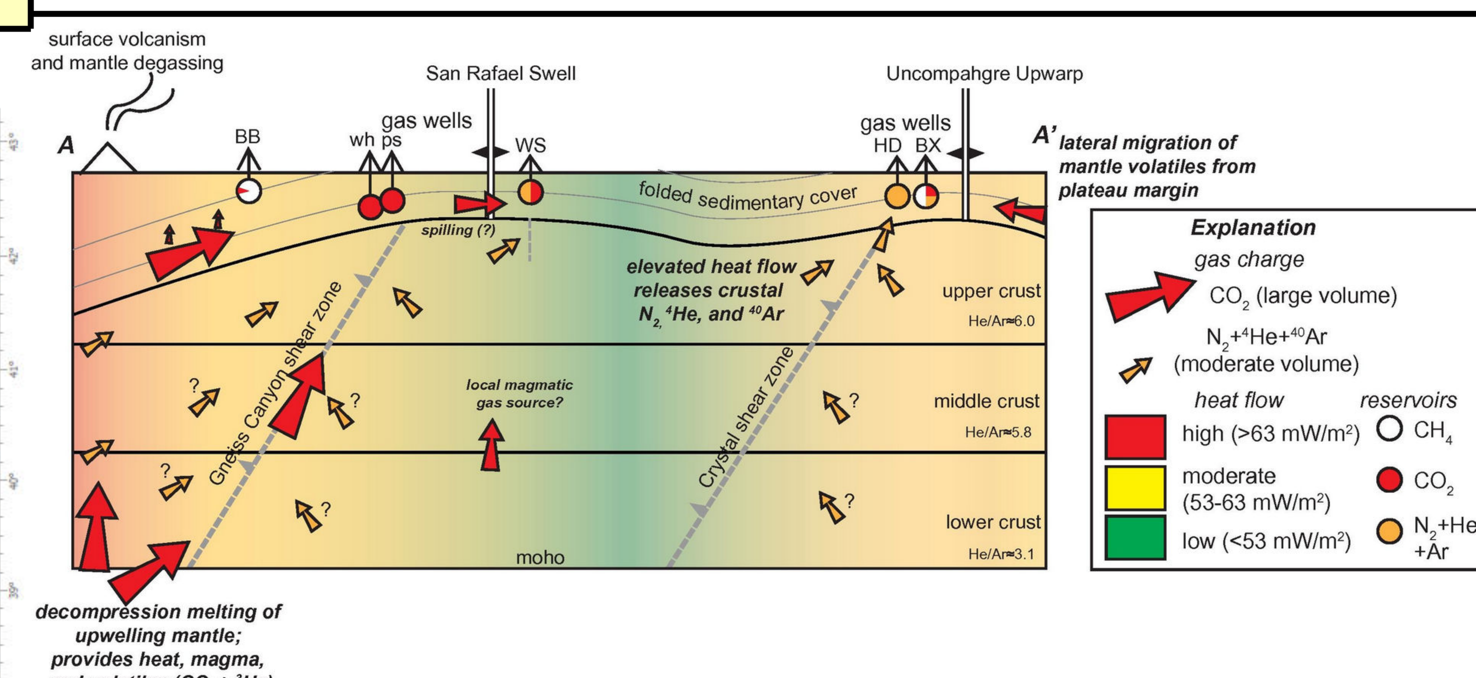
Research Questions

1) How does helium ultimately become associated within conventional petroleum systems?
2) How is helium extracted and produced in areas outside of BLM pipeline and storage access?
3) What areas of Utah are the most prospective for helium exploration?

Primary Migration and Accumulation of Helium

Although helium is the second most abundant element in the universe and the sixth most abundant gas in our atmosphere at ~5 ppm, it is extremely rare on Earth. Primary migration of helium in crustal basement rocks and accumulation in the overlying sedimentary strata is complex and may involve substantial heat, isotope fractionation, groundwater interaction and mantle degassing processes. The rare primordial isotope helium-3 (^3He) is best known as a byproduct in heavy-water nuclear reactors, but also may have been present since the formation of Earth. Helium-3 is not typically found in the gas stream unless the reservoir has received significant volumes from regional mantle degassing. Conversely, accumulations of the radiogenic helium-4 (^4He) isotope increases with time as the alpha decay product of various radioactive heavy elements, primarily uranium (U) and thorium (Th), sourced from granitic rock deep in the crust and, consequently, can occur frequently in trace amounts during the production of natural gas.

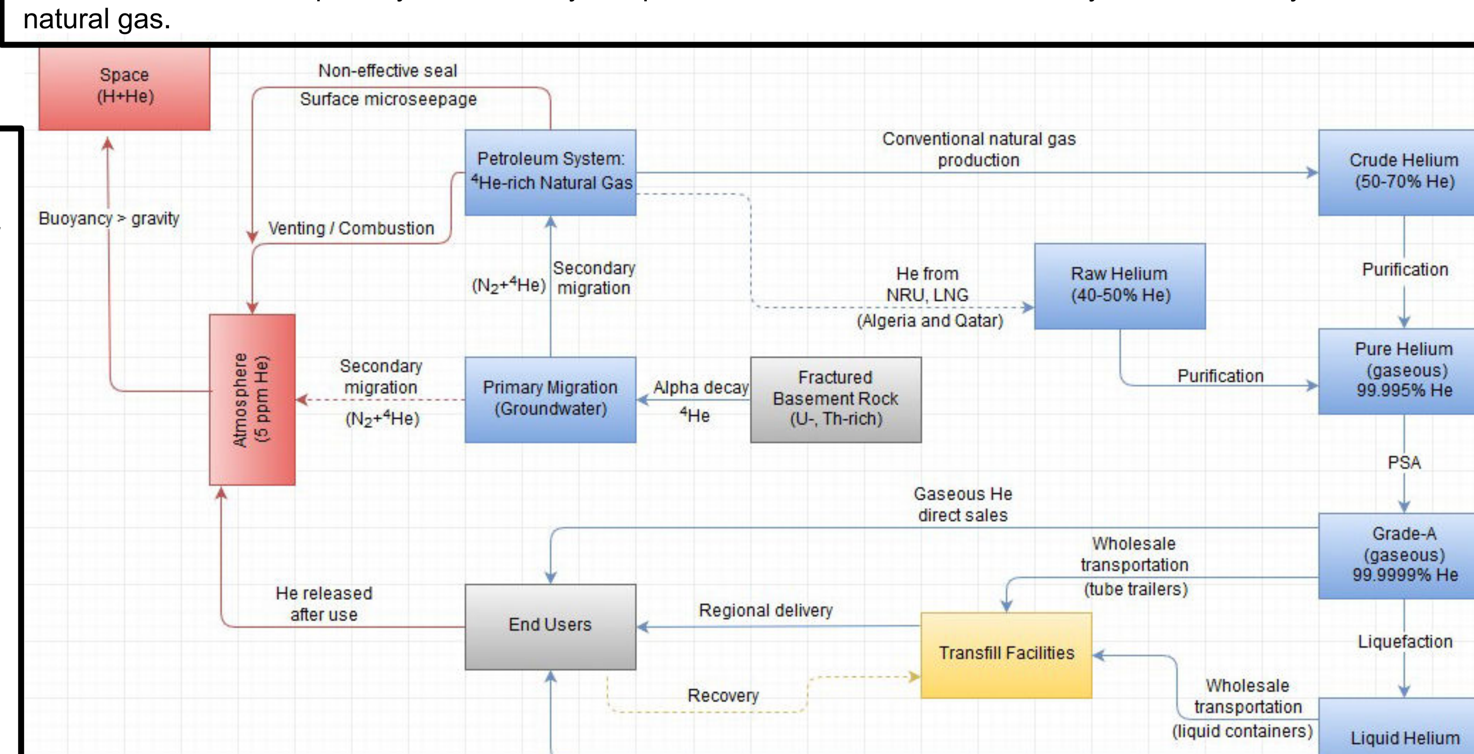
Basement-involved faults and associated fractures may provide pathways for helium microseepage to the surface where the buoyant gas gradually escapes beyond Earth's atmosphere. Following primary vertical migration at depth, helium may migrate laterally through more permeable formations in the subsurface. Equivalent to a conventional petroleum system, helium can be trapped in porous reservoirs sealed by impermeable salt layers or thick accumulations of shale.



East-west cross section (A-A') heat flow diagram spanning nearly 120 miles (~200 km) from Craddock and others (2017). Diagram depicts non-hydrocarbon gas migration in the subsurface due to mantle degassing and crustal radiogenic processes from the Wasatch line in central Utah to the Colorado state line. Cross section transects the Buzzards Bench (BB) field on the western, and the Woodside Dome (WS) field on the eastern, flank of the north plunging San Rafael Swell and continues through the northwest trending Uncompahgre uplift to intersect the Harley Dome (HD) and Bar X (BX) gas fields in east central Utah. Note Precambrian suture zones as possible migration pathways for helium and associated non-hydrocarbon gases. Along with mantle degassing processes, the upwelling mantle provides sufficient heat to the crust necessary to expel nitrogen from metamorphosed mica and radiogenic helium from heavier elements in the warm basement rocks where they are likely dissolved into and transported via groundwater interaction.

Helium Extraction and Production

Although extracting helium from the atmosphere is technologically possible, the current method to do so is vastly uneconomic. Natural gas fields capable of helium production have historically been discovered by accident during petroleum exploration. Non-hydrocarbon gases found in the gas stream are either considered a nuisance or an economic opportunity depending on commercial interest, volume concentration and field location. Alternatively, a natural gas rich in nitrogen with associated high concentrations of helium can improve the economics of the gas stream and may justify adding a helium recovery unit to gas processing. High purification and transportation costs of refined helium are the primary reasons why the production of helium has historically been driven by the demand for natural gas.

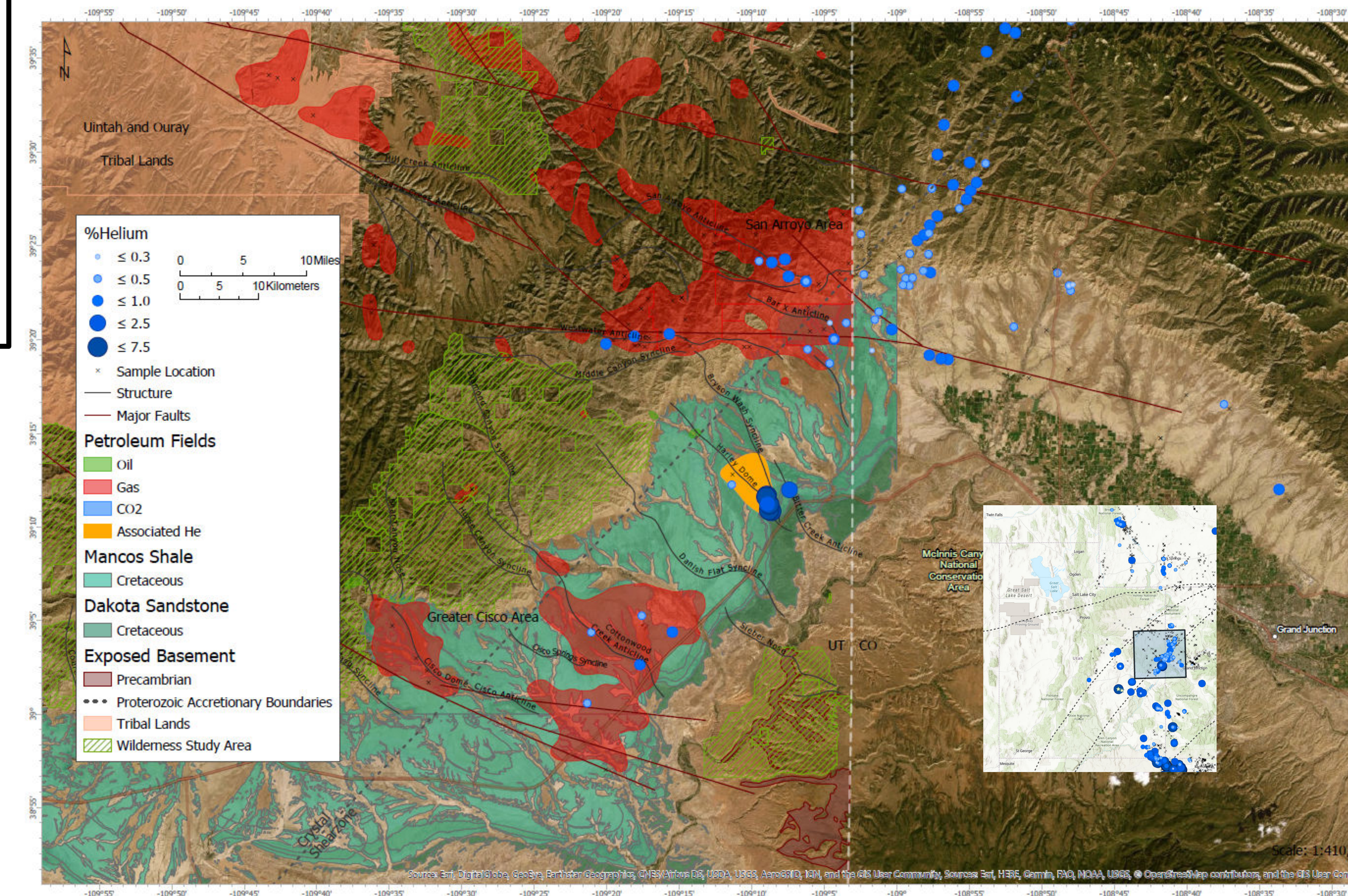


Flow of helium in the commercial supply chain illustrating important stages from initial crustal source rock to eventual escape beyond Earth's atmosphere. Modified from Grynia and Griffin (2016). Although concentrations vary greatly, both ^4He and ^3He follow the same general cycle after initial creation. Dashed-lines indicate helium flow processes that are either uncertain (e.g. secondary migration to atmosphere) or uncommon in the United States (e.g. He extraction from LNG and He Recovery). Pressure swing adsorption (PSA) units can be used to upgrade helium in large helium extraction plants or modified for smaller-scale helium exploration and production activities. Transfill facilities transfer bulk gaseous and liquid helium into smaller compressed cylinders to be more widely distributed.

Harley Dome field area, Grand County, Utah

High helium gas has been well documented at Harley Dome on the northwestern flank of the Uncompahgre uplift, between the San Arroyo gas field to the north and the Greater Cisco oil and gas field to the southwest. Multiple past and present shallow wells have penetrated and tested a host of Mesozoic sedimentary layers at or near the crest of the dome structure. The Jurassic Entrada Sandstone hosts the highest concentrations of helium (7.31% He) found in Utah and is associated with a nitrogen-rich gas stream (~85% N_2). With documented occurrences of helium microseepage in soil gas samples on and around Harley Dome from Seneshen (2018), it seems that the Harley Dome field lacks an effective seal, yet the source rock has supplied and maintained significant helium concentrations in the Jurassic reservoirs for nearly 100 years. With helium such an essential and valuable non-renewable resource, the leaking inert gas observed at Harley Dome should not be wasted, but captured at depth.

On the Colorado side, decent helium shows are located farther north, opposite the state line from the Utah San Arroyo gas field, but little to no oil and/or gas wells have been recorded on the majority of the Uncompahgre uplift as most of it falls within National Forest and Conservation lands. This likely has had a significant impact to the continuously high helium concentrations documented in natural gas and helium wells drilled at Harley Dome since the discovery well in 1925.



County	Field	API	Well Name	Legal	Lat	Long	Date Comp	Sample Date	Year Public	Fm Name	Age	Depth	Thick	Elev	BTU	CH4 %	H2S %	Ar %	CO2 %	N2 %	He %
GRAND	HARLEY DOME	4301930003	LANSDALE GOVT 4	SEC. 3, T19S, R25E	39.18093	-109.144	680617	680321	1969	ENTRADA	JURASSIC	836	30	4915	58	5.56	0	0	0.91	86.1	7.31
GRAND	HARLEY DOME	4301911514	HARLEY DOME 2	SEC. 4, T19S, R25E	39.18165	-109.147	260503	310518	1982	ENTRADA	JURASSIC	860	85	4946	92	5.5	0	0	0.8	84.6	7.06
GRAND	HARLEY DOME	4301950029	FLATIRONS FED 1-4	SEC. 4, T19S, R25E	39.19463	-109.149	130812	160321	2017	ENTRADA	JURASSIC	868	97	4945		7.55	0	0.4	1.29	83.64	6.82
GRAND	HARLEY DOME	4301930008	LANSDALE GOVT 13	SEC, 4, T19S, R25E	39.18687	-109.147	680604	680501	1969	ENTRADA	JURASSIC	946	56	4955	95	8.53	0	0	0.84	83.78	6.47
GRAND	HARLEY DOME	4301920247	LANSDALE GOVT 1	SEC. 33, T18S, R25E	39.19354	-109.15	671218	890804	1992	ENTRADA	JURASSIC	836	28	4889	529	49	0	0.2	0.1	46.5	2.51
GRAND	HARLEY DOME	4301930017	LANSDALE GOVT 15	SEC. 35, T18S, R25E	39.19984	-109.123	680915	890808	1992	ENTRADA	JURASSIC	915	43	4793	610	57.1	0	0.1	0	38.7	2.43
GRAND	HARLEY DOME	4301911513	BASHOR 1 / HOME OIL CO 1	SEC. 4, T19S, R25E	39.18721	-109.149	250912	290706	1982	MORRISON	JURASSIC	538	46	4942	571	50	0	0	0.3	43.8	2.25

Devonian-Mississippian Prospective Helium Play, Emery and San Juan Counties

Significant economic helium potential may exist within the extensive, yet relatively unexplored Devonian-Mississippian reservoirs of the Elbert Formation, Ouray Limestone and Leadville Limestone due to their close proximity to known helium-bearing basement rocks. This helium play contains nearly 40% of the wells with economic concentrations of helium (He>0.3%) in the gas stream found in Utah, with the majority sourced from the Mississippian Leadville Limestone. Trapped under multiple layers of Pennsylvanian salt and anhydrite, the Devonian-Mississippian helium play fairway encompasses much of southeastern Utah including the significant Temple Springs and Bow Knot helium prospects in Emery County, the Salt Wash field in Grand County and the Lisbon sour gas field area in San Juan County. On the Navajo Nation farther south, the Boundary Butte field area has significant helium shows from analyses taken within clastic reservoirs trapped between salt layers of the Paradox Formation.